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ENVIRONMENTAL NOISE ANALYSIS OF AGED CERAMIC INSULATOR UNDER INFLUENCE OF ELECTRICAL STRESS

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INVESTIGATIONS OF AGEING MECHANISM AND ELECTRICAL WITHSTAND PERFORMANCES OF THE FIELD AGED 132 KV PMU SKUDAI'S CERAMIC POST INSULATOR

NUR ATHIRAH BINTI THAZALI

A project report is submitted in partial fulfillment of the requirements for the award of the Degree of Master of Electrical Engineering

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JAN, 2013

I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledgement.

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The thesis has been examined on date 14 January 2013 and is sufficient in fulfilling the scope and quality for the purpose of awarding the Degree of Master.

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DEDICATION

To Mum, Dad and B.....

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In the name of Allah, the Most Gracious and the Most Merciful

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Nur Athirah Thazali, Jan 2013

ABSTRACT

This thesis presents investigation of 132kV field-aged ceramic post insulator, which has been in service 15 years old on a 132kV in PMU Skudai substation. Insulators are devices which are used in electricity supply networks to support, separate or contain conductors at high voltage. Aging of ceramic and post insulator materials is reviewed mainly from the standpoint of their interfacial performance. Insulating materials can be divided into simple ceramics. Aging processes are complicated in general, and take place under simultaneous multiple stresses such as electrical, mechanical and environmental stresses. Contact angle measured insulation under consideration leads to the surface is approximately horizontal to the top surface. The sheds also aged differently around their circumference and this is reflected in discoloration differences on different sides of the insulator, in addition to hydrophobicity changes. Voltage breakdown measurements carried out in the laboratory are also presented. Material analysis shows oxidation of the surface. Ageing effects were different uniform for each shed, the greatest oxidation being on the top surfaces of the sheds on the west and east side. Microscopy was found to be the most useful and effective tools for analysis of these ceramic insulator.

The measurements of the various parameters over the whole surface of the insulators are found to be consistent with each other and can be interpreted in terms of the chemistry of ageing and the longer term performance of the specific insulators in question. Two distinct types of ageing are identified. The role of solar radiation appears critical. In summary, the post insulators which have been in service for 15 years have very non-uniform surface properties in both the vertical and circumferential directions. There are some surface area at insulator has a moisture contamination at each creepage where found at all direction.

ABSTRAK

Tesis ini membincangkan tentang penyelidikan terhadap penebat seramik 132kV yang telah digunakan selama 15 tahun di pencawang masuk utama Skudai. Penebat adalah alat yang digunakan dalam rangkaian bekalan elektrik untuk menyokong, memisahkan atau mengandungi konduktor pada voltan tinggi. Penuaan bahan seramik dan penebat dikaji terutamanya dari sudut prestasi antara muka mereka. Bahan penebat boleh dibahagikan kepada beberapa jenis seramik. Penuaan proses yang rumit secara umum, dan mengambil tempat di bawah pelbagai tekanan seperti tekanan elektrik, mekanikal dan alam sekitar. Sudut sentuhan penebat diukur di atas permukaan adalah lebih mendatar ke atas permukaan. 'Shed' juga mempunyai jangka hayat yang berbeza di sekeliling lilitan dan ini ditunjukkan dalam perbezaan perubahan warna pada dua bahagian yang berbeza dalam penebat, di samping perubahan 'hydrophobicity'. Ukuran pecahan voltan yang dijalankan dalam makmal juga dibentangkan. Bahan analisis menunjukkan pengoksidaan permukaan. Kesan penuaan adalah berbeza dari keseragaman setiap 'shed', pengoksidaan terbesar berada di permukaan atas 'shed' di sebelah barat dan timur. Microscopy ditemui untuk menjadi alat yang paling berguna dan berkesan untuk analisis penebat seramik ini.

Ukuran pelbagai parameter di atas permukaan keseluruhan penebat didapati konsisten dengan satu sama lain dan boleh ditafsirkan dari segi kimia penuaan dan prestasi jangka panjang penebat tertentu. Dua jenis penuaan yang berbeza dikenal pasti. Peranan cahaya matahari adalah yang paling ketara. Ia menunjukkan bahawa arah angin, yang sangat konsisten dalam kawasan berkenaan, juga boleh menjadi satu peranan yang penting. Secara ringkasnya, penebat yang telah berkhidmat selama 15 tahun mempunyai sifat-sifat permukaan yang sangat tidak seragam di kedua-dua arah menegak dan lilitan. Terdapat pecemar di atas permukaan penebat pada seluruh arah.

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LIST OF SYMBOLS AND ABBREVIATIONS

V	-	Voltage
g	-	Gram
l	-	Litre
mm	-	Millimetre
cm	-	Centimetre
k	-	Kilo
°C	-	Degree Celcius
AC	-	Alternating current
SEM	-	Scanning Electron Microscopy
HV	-	High Voltage
UK	-	United Kingdom
UTHM	-	Universiti Tun Hussein Onn Malaysia
TNB	-	Tenaga Nasional Berhad
IEEE	-	The Institute of Electrical and Electronics Engineers
IEC	-	International Standard

CHAPTER 1

INTRODUCTION

1.0 Introduction

Insulators are devices which are used in electricity supply networks to support, separate or contain conductors at high voltage. The performance of an insulators used in overhead transmission lines, overhead distribution lines, and outdoor substations is a key factor in the reliability of power delivery systems. The insulating tools which are used in the maintenance of live apparatus, is included because of the many features in common with classical insulators. Solid insulators require long term dimensional stability, high electric strength, high mechanical strength, and an ability to maintain normal performance under polluted environments [1].

Aging of an insulator is the effect produced on it in field after a specified period of service. It is also one of the elements that damages post insulators but it is natural so it is classified under the name aging. Aging of ceramic insulators is mainly concerned with aging of outer sheath/shed. Outdoor weathering is a natural phenomenon which ages all materials to some extent. The most important properties of ceramic result from their high molecular weights. Their strength results from the entanglement of the ceramic chains. Degradation of ceramics is concerned with the breakdown of macro-molecules causing reduction in molecular weight. This breakdown can be caused by various environmental factors as stated below [2,3]:

- Biological Degradation
- Chemical Pollutants:- Sulpher dioxide, Oxygen, Ozone, NO2
- Environmental Stresses: - Heat, Light, Moisture.

1.1 Problem Statement

High Voltage (HV) polymeric insulators are replacing ceramic insulator commonly used for HV outdoor networks due to their ease of handling, reliability and cost. However, their long term performance and reliability are major concerns to power utilities. Outdoor insulators are subjected to electric stress and weather conditions such as rain, fog, heat and dew. These conditions increase the danger of leakage currents forming on contaminated or wet surfaces and finally leading to insulation degradation and failure. Therefore outdoor insulation materials must not only have to withstand the electric stress during usage, but also they must be resistant against ageing phenomena by dust or humidity. The ceramic insulators were widely used in the last decades because of high contamination resistance, lightweight, mechanical strength and hydrophobic attributes of the surfaces. Several different environment factors that affect the behaviour of 132kV ceramic post insulator materials conditions that caused the ageing process will be investigate.

1.2 Objectives

i. To investigate the electrical performances of field-aged 132 kV ceramic post insulator.
ii. To define the ageing mechanism that contributed the failure of the mentioned insulator.

1.3 Scope

In this project, the work has used the post ceramic insulator donated by TNB that have been in service. Several works have been done in achieving the objective such as:

i. The chemical analysis of contaminant spread on the surface using Scanning Electron Microscope SEM
ii. Hydrophobicity analysis of the contact angle was recorded with a digital camera and the data analysed by Vistametrix software
iii. HVAC experimental via standard dry and wet condition.

1.4 Limitation

i. The HVAC test needs to be done following parameters: voltage less than 90 kV and current not more than 3 A.

1.5 Chapter summary

The thesis consists of 6 chapters. Chapter 1 discussed about the introduction and aging of the insulator also state the problem statement, objectives and scope of the project.

Chapter 2 describes the broad overview of the studies on post insulators aged under field-aged and laboratory-aged conditions. The review includes the ageing mechanisms and test methods.

Chapter 3 describes the experimental process for non-electrical and electrical test.

Chapter 4 provides the details of the insulator and describes the results of visual observations, as well as on hydrophobicity.

Chapter 5 describes the results of electrical test on insulators by using distilled and salt water. The comparison of insulators before cleaning after cleaning is presents.

Chapter 6 discusses the ageing mechanisms and the ageing processes are discussed. The remaining lifetime of insulators are estimated from the status of hydrophobicity, surface properties and leakage performance. Describes ideas for future work. Some suggestions are also provided to encourage better evaluation of insulators in service and presents conclusions from the project.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

This chapter discussed about the broad overview of the studies on post insulators aged under field-aged and laboratory-aged conditions. The review includes the ageing mechanisms and test methods.

A true insulator is a material that does not respond to an electric field and completely resists the flow of electric charge. These materials are used in electrical equipment and structure as insulators or insulation [4]. All insulators have dual functions, mechanical and electrical, which commonly present conflicting demands to the design need. Their function is to support or separate electrical conductors without allowing current through themselves [5]. The term also refers to insulating supports that attach electric power transmission wires to utility poles or tower. Insulator for the purpose of this thesis, are device which are use on electric supply networks to support, separate or contain conductor at high voltage. Table 2.1 shows the numbers of reference that have been referred in completing this project.

Table 2.1: The numbers of reference that have been referred in completing this project

Author	Title of project	Description
Yu Xiong	Characterization of field-aged 400 kV silicone rubber composite insulators. (Xiong, 2006) [6]	A number of silicone rubber composite insulators have been removed after 15 years of service on a coastal 400 kV transmission line in the UK. Extensive analysis of their surface degradation is provided along with a description of their appearance. Material analysis shows cracking and oxidation of the surface. Ageing effects were far from uniform over each shed, the greatest oxidation being on the top surfaces of the sheds on the south side. Microscopy, EDX and FTIR were found to be the most useful and effective tools for analysis of these polymeric insulators.
R.S. Gorur	Contamination Performance Of Silicone Rubber Cable Terminations. (R.S.Gorur, 1991) [7],	Describes the results of a systematic study to understand the performance of silicone rubber terminations under contaminated conditions. The terminations evaluated were 15 kV class "cold shrink type for concentric neutral cables. They were evaluated in a fog chamber where experimental conditions, such as, the electric stress, water conductivity, water flow rate and the deenergization time between subsequent fog chamber exposures were varied in order to alter the test severity. Changes in the surface hydrophobicity were monitored periodically by analyzing the samples using ESCA (Electron Spectroscopy for Chemical Analysis), SEM (Scanning Electron Microscopy) and contact angle measuring techniques.
Muhammad Amin and Muhammad Salman	Aging Of Polymeric Insulators. (2006) [8]	This review describes the work done on aging of polymeric insulators. Introduction, design and, development history of different types polymeric insulators, Natural and Environmental factors that age insulators, man made factors that damage them, effect of each natural factor in detail and its remedy, artificial and field aging test setups dev eloped in different places in the world ,different techniques and methods of analysis used for detection of aging phenomena, results obtained from various aging sites about various parameters such as high temperature, rain, material additives, pollution, humidity, increased conductivity, sequence of aging phases as they appear in service mentioning affordable, unaffordable effects, service life prediction and testing Standards/Guidelines developed for polymeric insulators.

T. Tanaka	Investigation the aging of polymeric and composite insulating materials aspects of interfacial performance. (T. Tanaka, 2002) [9],	Ageing of polymeric and composite materials is reviewed mainly from the standpoint of their, interfacial performance. Insulating materials can be divided into simple polymers and composites. Polymers for power cables, transformers, insulators and rotating machines consist of thermoplastics such as PE, PET and PPS, elastomers such as silicone, EPR and EPDM, and thermosets such as epoxy. Composites for GIS, rotating machines and insulators comprise epoxy/ glass, epoxylsilicalalnmina, and epoxylmica systems. Aging processes are complicated in general, and take place under simultaneous multiple stresses such as electrical, thermal, mechanical and environmental stresses. Some of the phenomena covered in this paper are associated with the degradation by tracking and erosion and the loss of hydrophobicity in case of surface properties, and with PD, electrical treeing, water treeing and combined phenomena. The quality of cable insulation such as XLPE has been improved extensively from the standpoint of design electric strength. Interfacial problems will emerge for modification of cable joints. It is expected that polymers for outdoor use and filled epoxy resin systems should be improved from their environmental stability and from their design stress enhancement, respectively.
R. S. Gon	Aging In Silicone Rubber Used For Outdoor Insulation. (1992) [10]	Ageing is indicated by permanent changes. The analytical techniques used to study the permanent changes are, Fourier Transform Infra-Red FE) Spectroscopy, Energy Dispersive X-Ray (EDX) Analysis, X-Ray Diffraction (XRD) and Surface Roughness Measurement. This paper highlights the fact that there are permanent changes occurring in the material that lead to progressive degradation in the long run, even though there can be a complete recovery of surface hydrophobicity in a short time.
S. M. Rowland	Surface ageing of HV composite insulators on 400 kV lines. (2007) [11]	The market for polymeric insulators has now existed for over 20 years enabling a comparison to be made between good-quality service-aged products and the original expectations of performance. This paper presents investigations of field-aged composite silicone rubber insulators, which have been deployed for 15 years on a 400 kV transmission line in a coastal region of the UK. Measurements of contact angle, and surface chemistry through energy dispersive X-ray analysis (EDX) and Fourier transform infrared spectroscopy (FTIR) are given. Evidence is presented of substantial variations of key surface properties along the length and circumferentially around the insulator. Ageing mechanisms and processes are discussed in this context.

2.1 Type of insulator

The insulators play one of the key roles in provision of safe transmission of electric energy and minimization of energy loss. By application the insulators of the following types as suggested by Holtzhausen (2008) is shown in Figure 2.1 [12]. Insulator however may be built from different kind of material to meet the design requirement in term of application, climate, strength-to-weight ratio and many more. The most common material that has been used in constructing the insulator is polymer and porcelain. The main advantages of the polymer insulator are improved corrosion resistance of outer polymer insulation under conditions of polluted air, reliability and endurance in the wide range of mechanical loads and temperature changes, light weight, significant savings achieve during assembly and replacement, vandal-proof design and so on [13]. In Malaysia, ceramic insulator is commonly used in many area compared to polymeric insulator. Polymeric insulator is newly introduce hence it is not widely used but it slowly replacing the ceramic type insulator.

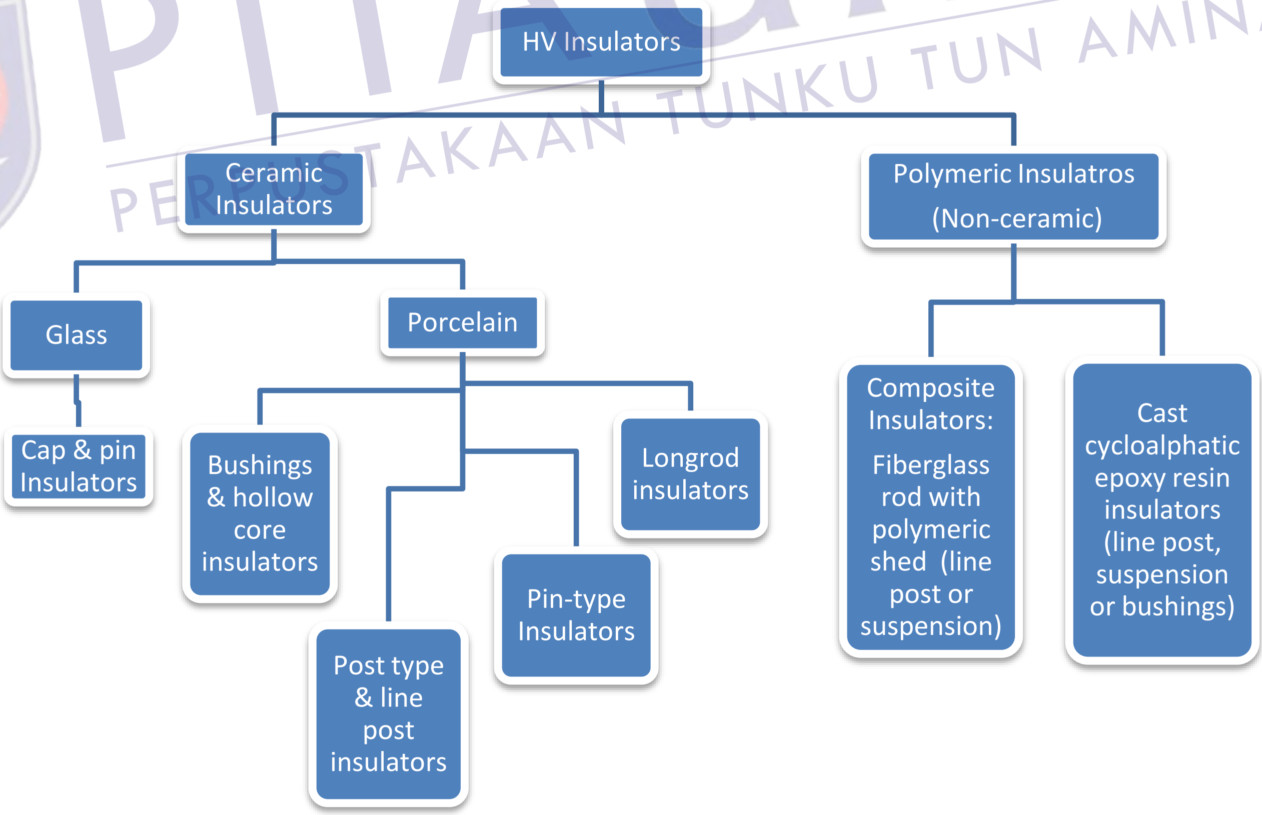
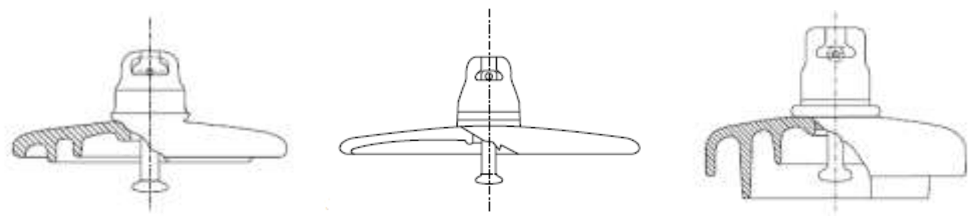


Figure 2.1: The classification of power line insulators

Given the material based the type of design, the protective mould material, voltage class and mechanical destructive power determines the type of the insulator. Figure 2.1 shows the classification and type of the insulator commonly used in power system. There is two of most commonly used material that is ceramic which comprise of glass and porcelain and polymeric or non ceramic type.

2.1.1 Ceramic Insulator

Ceramic insulators are made of ceramic materials which include porcelain and glass. Their initial use precedes the construction of power systems. They were first introduced as components in telegraph networks in the late 1800s [14]. There are a number of basic designs for ceramic insulators; examples were shown in Figures 2.2 (a), (b) and (c). Porcelain is used for the production of cap and pin suspension units, solid and hollow core posts, pin type, multi-cone and long rod insulators, and bushing housings. Glass, on the other hand, is used only for cap and pin suspension and multi-cone posts [15, 16, 17]. Porcelain and glass insulators are well established, as might be expected based on their long history of use. Currently these types of insulators comprise by far the majority of in-service units. Continuous improvements in design and manufacturing processes have resulted in insulators, which are both reliable and long lasting. Porcelain units are coated with a glaze to impart strength to the surface. Today's glass insulators are predominantly manufactured from thermally toughened glass, which prevents crack formation. Both of the materials have inert surfaces, which show very good resistance to surface arcing, and both are extremely strong in compression.



(a) (b) (c)

Figures 2.2: (a): Typical constructions of ceramic type suspension insulators (a) Standard. (b) Open profile (self-cleaning). (c) Anti-fog and for d.c applications [16

2.2 Factors influencing the aging of insulator surface.

Insulator in service is in general exposed to a lot of factors of influence. A so called multifactor stress results from at least two simultaneous stress factors, such as temperature, environmental, mechanical and electrical stress, which cause special aging effects. In order to get information about the performance of electrical insulation systems under multifactor stress, electrotechnical committees have established guides for multifactor stress functional testing. While in the meantime a lot of well accepted multifactor stress testing procedures have been worked out, fundamentals of the surface aging of organic solid insulation due to high electrical stress and low surface conductivity, resulting from condensation or wetting and/or low contamination, are still under investigation. Figure 2.3 suggests the aging mechanism of the insulator.

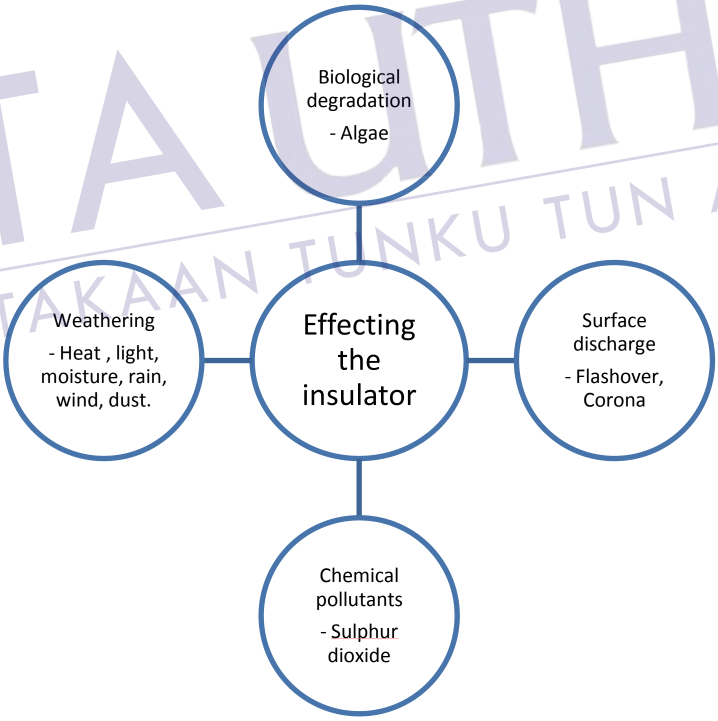


Figure 2.3: The aging mechanism of the insulator.

2.2.1 Biological degradation

Since polymeric insulators are made up of organic materials and all organic materials more or less have property to support the growth of biological microorganisms on them. Microorganisms colonize the surface in the form of Biofilms.

The requirements for formation of Biofilms on a surface are rather simple, only water, nutrition and microorganisms should be present. Microorganisms are always present outdoors and nutrients may come from the material itself or from its surroundings. Adhesion to surfaces is a common microbiological strategy for survival in low nutrient environments and Biofilms can thus be found in a wide range of environments. This is in direct consequence with the reports on biological growth on outdoor insulators, which reveal that, microbiological [18,19] colonization of ceramic as well as composite insulators takes place in all parts of the world. The biological elements that can grow on surface were not known fully until recent researches on 'Growth on insulators' have identified most widely grown microorganisms as algae, fungi or lichen.

Algae is a simple plant, producing its food by photosynthesis it has six categories; blue-green (Cyanophyta), green (Chlorophyta), Yellowgreen (Xanthophyta), brown (Phaeophyta), red (Rhodophyta) and Diatoms (Bacillariophyta). Algae are found almost everywhere, even in arctic climates. They spread through water, wind and animal movements, and multiply under certain climate conditions, i.e. favorable temperature, humidity and sun irradiation.

2.2.2 Effects caused by biological deterioration

There are several different ways in which microorganisms can influence the structure and function of synthetic polymers covering the composite insulators. The five major effects are Fouling (contamination), Degradation of leaching components, Corrosion, Hydration, and Discolouration.

Fouling is an unwanted deposition and growth of microorganisms on surfaces. The surface does not need to support growth or to be affected, but the presence of the Biofilms may interfere with the function and the properties of the material, such as masking hydrophobicity or increasing surface conductivity.

Degradation of leaching components. Additives, fillers, and unreacted material leaching out of the polymer may provide a food source for the microorganisms in the Biofilms. Consumption at the surface leads to concentration gradient flow from in-side of polymer to surface, leading to subsequent deterioration. For instance, consumption of plasticizers leads to mechanical degradation of the remaining polymer through increased embitterment and loss of mechanical stability.

Corrosion is a process that is strongly influenced by the local conditions at the surface. Biofilms give rise to gradients in pH value, redox potential, concentrations in oxygen and salts, and all this influence parameters relevant to corrosion at the surface. The degradation involves reactions initiated by free radicals and extra cellular enzymes, generated by fungal metabolism. This ability of fungi of secreting a number of extra cellular enzymes, as well as its ability to easily colonize surfaces, both contributes to a rapid degradation of materials. These reasons make fungi especially relevant in bio resistance tests.

Hydration is penetration of water in a material. Due to the fact that Biofilms mainly consist of water, they act as electrolytes increasing conductivity of surfaces. Fungal and mold growth on circuit boards and in computers have been found to cause short circuits and subsequent failure of electronic equipment. In a similar way conductivity of ceramic materials is also increased through penetration of water. It leads to high leakage currents which at the same time reduce mechanical stability.

Biofilms contain organisms that produce pigments causing serious discoloration. Some pigments, especially the ones produced by certain fungal spices, are known for easily defusing into lipophilic polymers, such as PVC. This discoloration is not removable through cleaning. Further, some microbial degradation products cause severe problems due to odour [8].

2.2.3 Effect of environmental

Heat, light and moisture produced by environment effect an in service insulator. Heat and light produce surface cracking and erosion. In absence of light, most polymers are stable for very long periods at ambient temperatures. The effect of sunlight is to accelerate the rate of oxidation. Photo oxidation leads to chain scission of hydrophobic methyl groups leading to the production of aldehydes, ketones and carbolic acids at the end of ceramic chains. The breakdown may be comparatively mild, affecting only side groups, or it may be of a severe nature, causing a reduction in the size of macromolecules. Considering that even one chain scission per molecule in a polymer with a molecular weight of 100,000 destroys its technical usefulness [20]. The moisture goes into these cracks and finally causes a flash under of the rod.

2.2.4 Effect of corona

Corona discharges occur on the surface when electric field intensity exceeds the breakdown strength of air, which are around 15 kV/cm. Atmospheric conditions which effect corona generation are air density and humidity. The geometry of insulator itself has a role in the initiation of corona activity. The corona generates ultraviolet light, heat, and gaseous by products (ozone, NO_2).

The corona discharges subject the insulator to severe electrical strains and chemical degradation. Continued degradation may render the ceramic ultimately unusable. A polymer insulator must have the right chemistry to be able to withstand this chemical degradation throughout its service lifetime. The other undesirable effects of corona are noise generation, TVI, RI, ozone generation and the loss of energy.

When corona generation occurs on a wet surface, this results in 'wetting corona activity'. Wetting corona activity is the outcome of a non-uniform wetting causing high electric field. This activity depends on the type and magnitude of wetting as well as on the intensity of surface electric field. The magnitude of wetting depends on the surface characteristics (hydrophobic or hydrophilic) and on the type of wetting whether it is produced by rain, mist, fog or condensation. Magnitude of surface electric field depends upon the dimension of grading ring, its position, live-end hard wares and end fittings.

Wetting corona activity occurs mainly at live and ground terminals. Lower hydrophobicity makes discharge activity more likely. Besides the undesirable effect discussed earlier, corona in the presence of water generates nitric acid ($NO_2+H_2O=HNO_3$) which may cause surface deterioration [21].

Wind, dust, rain and salt precipitation all these factors can change the insulating material physically by roughening and cracking and chemically by the loss of soluble components and by the reactions of the salts, acids, and other impurities de-posited on the surface. Surfaces become hydrophilic and water penetrates in the insulating materials causing material breakdown.

2.3 Electrical stresses on insulators

This section discussed the surface roughness due to electrical stress on insulator is power frequency, impulse electrical and environmental stresses.

2.3.1 Power frequency electrical stresses

Each component of the power system is designed to withstand a continuous high voltage with high reliability. The voltage stress on insulation is defined over which a gradient, typically in kilovolts per meter (kV/m). The distance over which this voltage gradient is measured can vary from a few millimetres for microgap corona discharge, up to ten meters for the space between phases of an EHV transmission lines.

For ac systems, it is most common to consider the line-to-ground root-mean-square (rms) voltage across the insulator terminals. The peak voltage is related to the rms voltage by a factor of $\sqrt{2}$. The line-to-ground voltage is related to the system voltage by a factor of $\sqrt{3}$ in three phase systems. For distribution systems, with a typical designation of 27.6/16kV, the second value indicates the line-to-ground voltage on single phase lateral circuits. For dc systems with ripple, the peak voltage should also be used to establish insulator stress.

2.3.2 Impulse electrical stresses

Overvoltage impulses generated by lightning or switching impose a higher, albeit momentary stress on the insulator. For both lightning and switching impulses, electrical flashover voltage is mainly dependent on the dry arc distance, that is,the shortest air distance between the conductor and the grounded part of the insulator.

Insulation coordination for HV system with voltages less than 230kV is dominated by lightning performance in insulation coordination guides. Insulation coordination of higher voltage levels, including EHV systems with higher reliability requirements, is dominated by switching-surge control using protective devices such as arrester or closing resistors. However, regardless of the line voltage, insulator selection for polluted areas take careful note of the contamination performance to provide adequate leakage distance.

Under switching-surge conditions, the transient voltage wave has rise time and time-to-half-value of 250µs and 2500µs respectively, rather than 1.2µs and 50µs for lightning impulse voltage. This means that predischarge activity is important for switching surges. There is normally a lower switching-impulse flashover gradient for rod-to-rod gaps than either ac peak or lightning gradient.

The effects of metal structures near the air gap for switching surges are relatively strong and lead to the use of gap factors that are multiplied by the basic switching impulse insulation level (BSL). This subject is covered in excellent detail in Hileman [199]. The BSL for the rod-to-rod gap is used without gap factors to establish the suitable electrical clearances around high voltage tests in IEEE Standard 4 [1995]. Normally, switching-surge stresses are expressed in a per-unit system based on the crest value of the line-to-ground voltage.

2.3.3 Environmental stresses

Conventional air-insulated substations represent a large majority of installed high-voltage substations. They range in voltage from distribution levels to 500 kV systems. The external insulation generally utilized in these outdoor substations takes the form of insulators (posts, suspension and pin types) and housings. These types of apparatus are generally broken into classifications based on manufacturing and materials.

Insulators exposed to the environment collect pollutants from various sources. Pollutants that become conducting when moistened are of particular concern. Two major sources are considered:

Coastal pollution: the salt spray from the sea or wind-driven salt laden solid material such as sand collects on the insulator surface. These layers become conducting during periods of high humidity and fog. Sodium chloride is the main constituent of this type of pollution.

Industrial pollution: substations and power lines near industrial complexes are subject to the stack emissions from nearby plants. These materials are usually dry when deposited; they may then become conducting when wetted. The materials will absorb moisture to different degrees, and apart from salts, acids are also deposited on the insulator.

Wind is instrumental in the deposition process. High humidity, fog or light rain cause wetting of the pollution layers. Heavy rain removes the pollution layer especially on the upper sides of the sheds.

Insulators in service become covered with a layer of pollution. When the surface is dry the contaminants are non-conducting; however, when the insulator surface is wetted by light rain, fog, or mist, the pollution layer becomes conducting with the following sequence of events:

1. Conducting layer build-up
2. Dry band formation
3. Partial arcing
4. Arc elongation
5. Eventual arc spanning the whole insulator followed by flashover

The pollution layer in general is not uniform. When conduction starts, the currents are in the order of several milliamps, resulting in heating of the electrolyte solution on the insulator surface. The leakage current begins to dry the pollution layer and the resistivity of the layer rises in certain areas.

This leads to dry band formation, usually in areas where the current density is highest. The dry band supports most of the applied voltage. The air gap flashes over, with the arc spanning the dry band gap which is in series with the wet portion of the insulator. The arc may extinguish at current zero and the insulator may return to working conditions. Dry band formation and rewetting may continue for many hours. The current coinciding with the occurrence of dry band breakdown is in the order of 250mA. The current at this stage is in surges, and the voltage is unaffected.

2.4 Failure modes of insulator

Flashovers, caused by air breakdown or pollution, generally do not cause physical damage to the insulators and the system can often be restored by means of auto closing. Some other events, however, cause irreparable damage to the insulators. There are many types of failure modes of insulator and Figure 2.4 shows the examples with graphical image embedded.

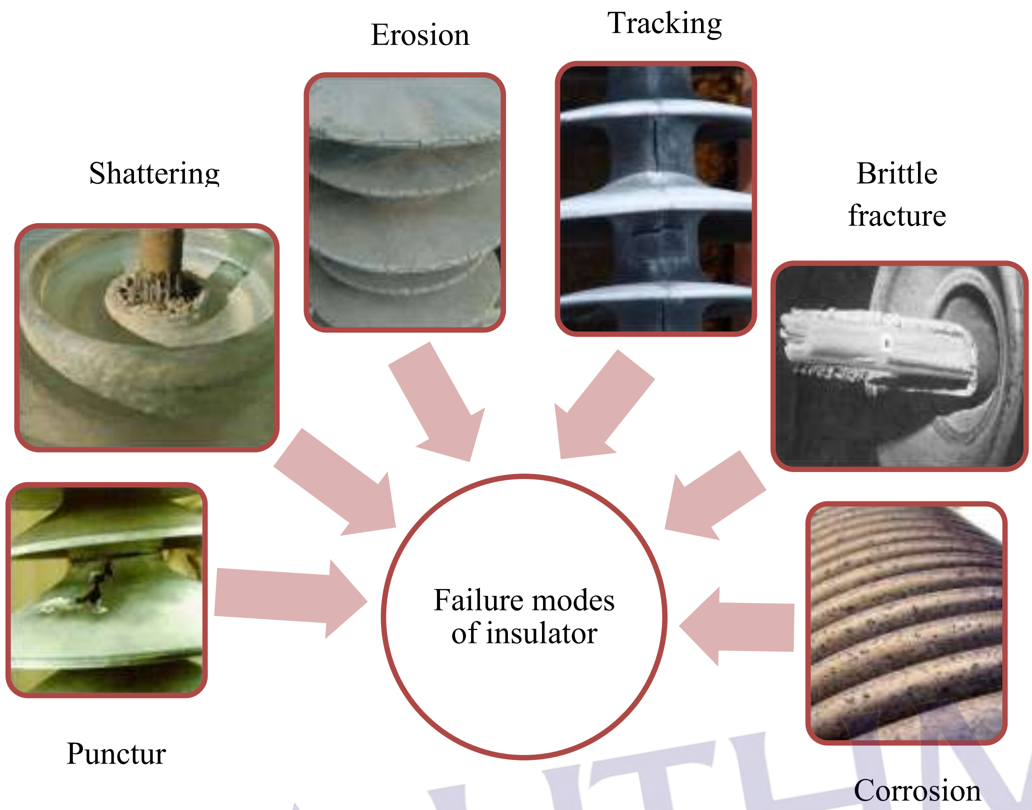


Figure 2.4: Failure modes of insulator

2.5 Analysis and testing of the insulator

The investigation of the filed-aged insulators is analysis the chemical of the contaminant surface, hydrophobicity, electrical test and flashover test. Surface analysis is done by taking a visual and investigates the surface observation, analyze the contaminant weight and analyze the contaminant by using Scanning Electron Microscopy SEM and the hydrophobicity.

2.5.1 Chemical analysis

Certainly, direct visual examinations on the change in colour, roughness, cracking, burning, treeing, erosion, pollution, etc., are the most common and easiest way to make an assessment on the aging of composite insulators. Usually, after aging there are significant visual changes, though many of these, for example colour, do not carry helpful information about electrical performance. For a detailed research, optical microscope or scanning electron microscopy can be used to discover the changes on insulator surface [22].

2.5.2 Hydrophobicity

Hydrophobicity is the most important property of insulators and many effects have been paid to the measurement of this property. With the help of static or dynamic contact angles, sliding angle or water soaking tests, hydrophobicity could be quantified and the contact angle measurement may be the most commonly utilized method to reach the assessment. The choice of liquids used is somewhat not consistent, but usually distilled water or methylene iodide has been considered [22].

2.5.3 Electrical test standard

To determine the long-term reliability of insulators, it is preferable to use accelerated ageing tests to know the relative performance of any type of insulator. To understand the detail of the precise mechanism of surface degradation, tests of materials and whole insulators have also been conducted without any electric stress or surface pollutant present, by subjecting insulators to an environment which simulates the action of the highly oxidative species generated by small electrical discharges in service conditions. Results from this approach have proven accurate in predicting comparative degradation rates of insulators in service conditions when the main ageing influence is surface discharging. The test standards include: Salt fog test (IEC 60507), the continuous testing standard (IEC 61109) and the dry layer method.

a) Salt fog test (IEC 60507)

The salt fog test used two columns of spray nozzles, opposed at 180º and facing the axis of the insulator from a range of 3 m. The test object is thoroughly wetted with clean tap water. The saline fog system, supplied by water of the prescribed salinity, is started when the test object is still wet. The voltage is applied to the test object simultaneously, raised rapidly to the specified value, and kept constant during the specific time, usually 1 hour or until flashover occurs. This procedure is repeated several times. Before each procedure, the test object is thoroughly washed with clean tap water to remove any trace of salt. Each nozzle is fed with salt at 0.5 litre/min and with oil-free compressed air at 7kg/cm². The withstand salinity of the tested insulator is defined as the highest concentration salt, in kg/m3, which is withstood without flashover for three out of four tests at rated working voltage. Pre-conditioning of the test object by a number of flashovers during the application of contamination is recommended before the real test begins. Even this pre-conditioning should be followed by a washing. Leakage current is also monitored in the salt fog test. The parameters of the salt fog have different effects on the results of flashover voltage and leakage current [1].

b) Environmental test (IEC 61109 test)

These tests are in addition to the highest voltage of the power system frequency, various pressures in a way that the repeated including simulated solar radiation, artificial rain, dry heat, wet heat, high humidity at room temperature and low salinity salt fog. Rain and salt fog is in accordance with IEC standards. Simulated solar radiation obtained with xenon arc lamp 5000 W spaced in time about 48 cm of insulation. The proposed period for the whole test is 5000 hours. Many studies have been conducted in accordance with IEC 61109 test [6].

c) Clean fog test method

The clean-fog method is the contaminating coating is allowed to dry and the test object is then usually placed in a special test chamber. A fog produced by normal tap water and air, or a steam generator, is used, to wet the contaminating layer gradually until its surface resistivity reaches a minimum value. The voltage is applied immediately thereafter, raised to the specific value, and kept constant until flashover occurs or withstand is apparent. This may be 15 minute or, in the case where a steam generator is employed, as long as 2 hours. Some tests are performed on the samples of the test materials to determine the most promising compound for use in subsequent tests on complete insulators. These tests include the inclined plane test (IEC 587), method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions (IEC 112), Dust and Fog Test (ASTM 2132); Rotating Wheel Dip Test (IEC 1302).

d) Dust cycle method

The fog and rain phases are followed by the so called "wet phase" where the test object is subjected to sustained humidity for a while to stimulate the discharge activity. If no flashover has occurred during this phase the test object is dried in the air flow. The test result is the number of cycles to flashover. During the cycles it is complemented by continuous leakage current measurements. Directly after the test the ESDD (equivalent salt deposit density), NSDD (neutral solid deposit density) and hydrophobicity are measured on the test object. Visual aids are e.g. video recording of the location and intensity of discharge activity and photographs of the surface after test [30].

e) Dry salt Layer (DSL) method (IEC 507)

The insulator shall be thoroughly cleaned by hand wiping with a strong detergent before the test, to remove all traces of grease from the insulator surface. The hydrophobicity of the surface shall be checked to secure a completely hydrophilic surface. This guarantees the worst case and is one condition to obtain a repeatable test method. After the conditioning the insulator is left to dry before the pollution phase starts. (Clean, pressurized air may be used to accelerate the drying) [31].

Salt is sprayed from one direction towards the insulator to simulate the dominating wind direction close to the sea. The pressure of the air flow, the flow rate of the salt solution and the distance between the test object and the nozzles are adjusted in such a way that the salt is dry, when it reaches the insulator surface. The wetting of the energized polluted insulator is performed by a steam fog during 100 minutes. If leakage current measurement or other techniques indicate a clear decrease of discharge activity and a negligible risk for flashover, the test may be ended within the prescribed test time, to be agreed upon during the test. The insulator is cleaned using a high water pressure device to remove the remaining salt. The hydrophobicity of the insulator should be checked after the cleaning.

2.5.4 Flashover test

The flashover is due to a breakdown of air at the insulator surface, and is independent of the material of the insulator. As the flash-over under wet conditions and dry conditions differ tests such as the one minute dry flashover test and the one minute wet flashover test are performance. 50 percent dry impulse flashover test, using an impulse generator delivering a positive 1/50μs impulse wave. The voltage shall be increased to the 50 percent impulse flash-over voltage (the voltage at which approximately half of the impulses applied cause flashover of the insulator). Dry flash-over test applied when the voltage is raised to this value in approximately 10 seconds and shall be maintained for one minute. The voltage shall then be increased gradually until flashover occurs. When wet flash-over test, this the insulator is sprayed throughout the test with artificial rain drawn from source of supply at a temperature within 10 degrees of centigrade of the ambient temperature in the neighbourhood of the insulator. The resistivity of the water is to be between 9,000 and 11,000 ohm cm [32].

2.6 Testing and specifications

All insulators are tested according to standard procedures outlined in various national and international publications. Ceramic and glass insulators are mechanically and electrically proof tested prior to shipment. In the case of polymeric insulator, prior to leaving the factory each production piece is subject to mechanical but not to electrical proof testing. The primary reason for this difference is that ceramic and glass units are generally made of a number of smaller units in series [23]. Performing electrical tests on each unit would require significant time and investment in a sizeable high voltage test facility. In addition to mechanical and electrical proof tests, the raw materials used in the production of polymer insulators are tested as a control on the production process. With regards to qualification and application testing, the most widely used standards are those issued by IEC, ANSI, IEEE, CSA, and CEA [24]. Depending upon the type of insulator, the electrical tests include wet and dry power frequency flashover, lightning impulse flashover, steep front impulse flashover, power arc, and corona tests. Mechanical tests include tension, thermal mechanical cycling, torsion, cantilever, and electrical–mechanical testing. Contamination performance tests are also performed on these insulators [25].

CHAPTER 3

METHODOLOGY

3.0 Overview

This chapter overall conclude all the work progress and method that have been done in order to achieve the desire objectives. The flowchart in figure 3.1 shows the working order to achieve the objective of this research.

All work is divided into two phase that is phase A and phase B. Phase A representing all the work that being done in Master Project 1 (PS 1) and phase B will reflect all the work that being done in Master Project 2 (PS 2). The progress of the project will be displayed in a form of diagram to ease up the understanding and to express the technical work fluently.

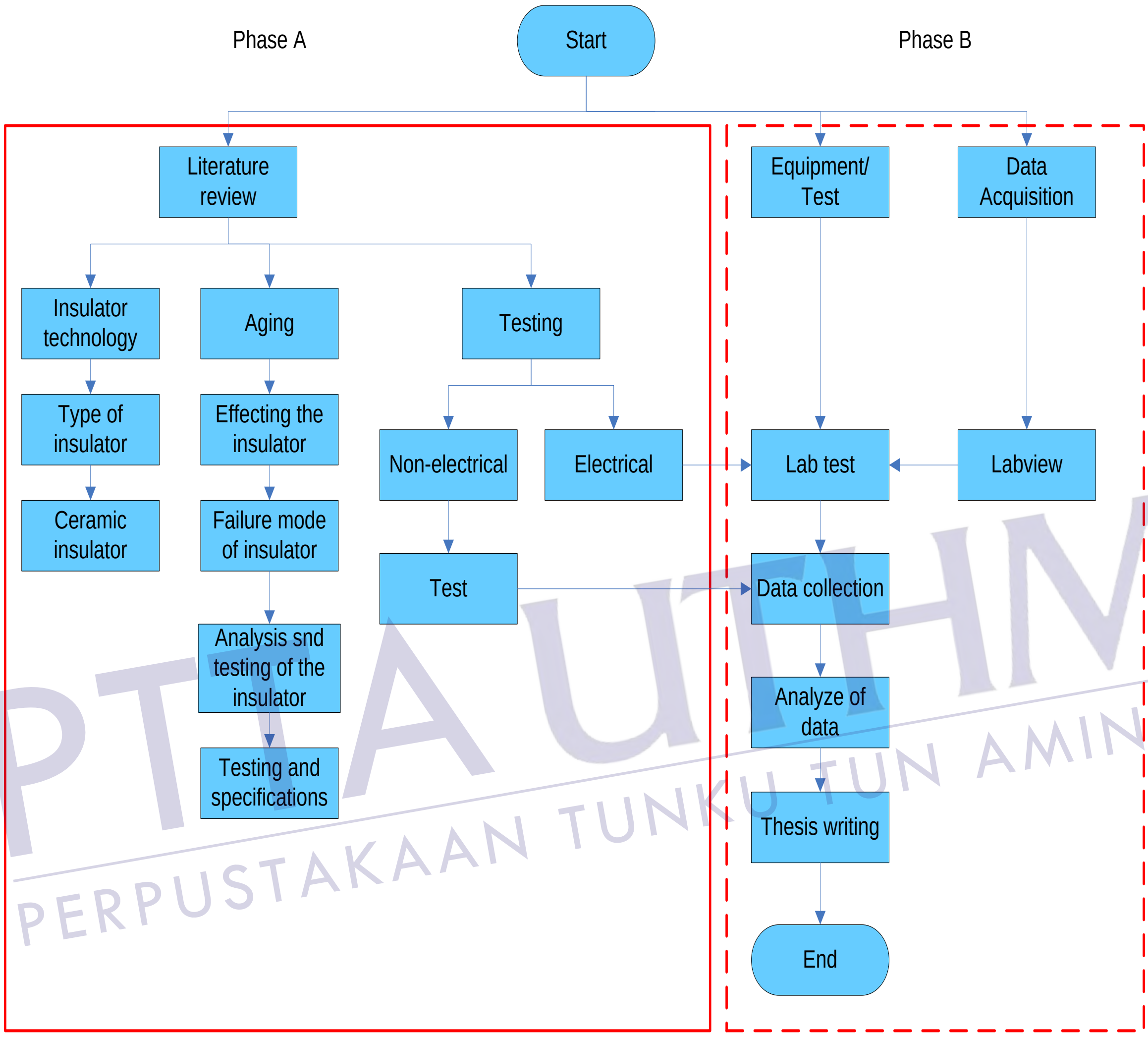


Figure 3.1: Overall Progress Flowchart

3.1 Experimental process

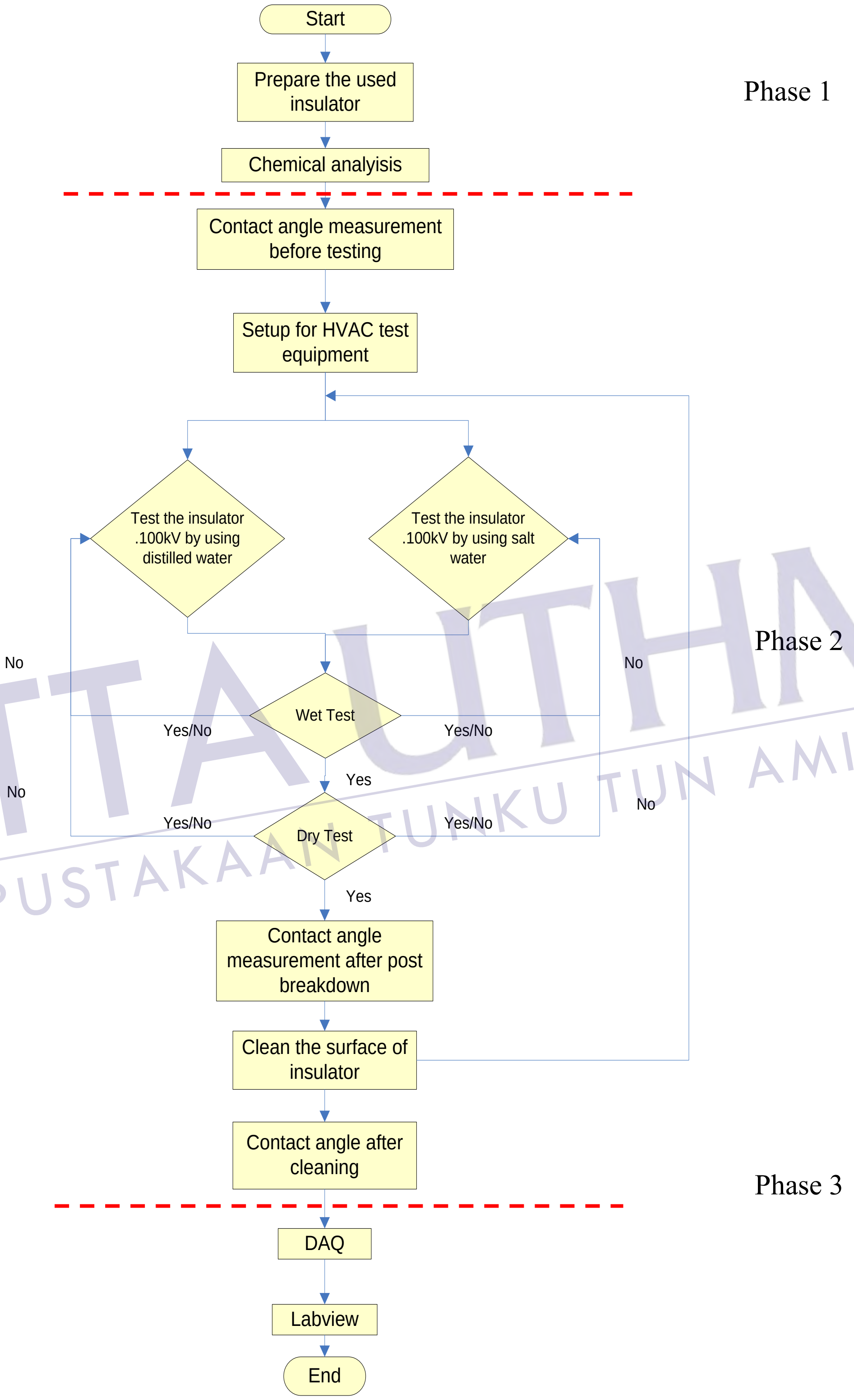


Figure 3.3: Experimental process

3.2 Phase 1

The sample of insulator will be use for this experiment. Before a test is conducted, correct testing equipment configuration for the test that is going to be conduct is crucial. The chemical analysis done with by taking a visual and investigates the surface observation, analyse the contaminant weight and analyse the contaminant by using Scanning Electron Microscopy SEM. The configuration of the equipment can affect the data that is shown by the test.

3.3 Phase 2

Contact angle data was taken before testing process, after the post breakdown and after cleaning the insulator. The configuration of test can be referred to the test set manual that is provided by the equipment manufacturer. In this case the manufacturer is TERCO and known as TERCO high voltage laboratory. The configuration of the test equipment can be seen in Figure 3.4. The panel is connected to HV transformer which high tension winding that is connected to a measuring resistance and measuring capacitance. The test subject is connected in parallel with measuring capacitance and series with measuring resistance. Figure 3.4 shows the actual equipment configuration [26].

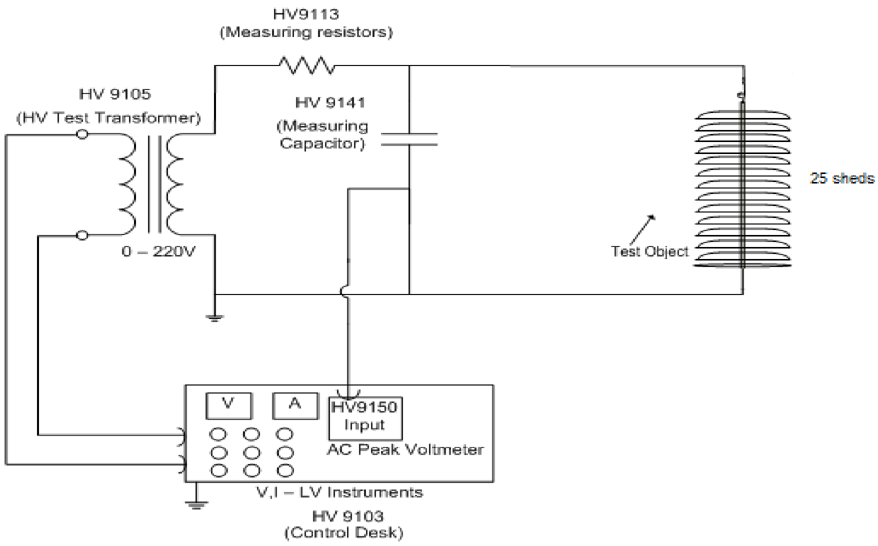


Figure 3.4: Configuration of the test equipment

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